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Paper Session II-A - A New Commercial Space Furnace-Developed on the Fast Track

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"A NEW COMMERCIAL SPACE FURNACE—DEVELOPED ON THE FAST TRACK"

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ABSTRACT

A new space payload was recently developed which provides the capability for processing advanced metals and alloys. This payload features a high temperature sintering furnace which has successfully flown on the first two missions of the commercial SPACEHAB payload carrier (STS Mission 57 and 60). This paper describes the technical and programmatic approaches used to deliver the rack-mounted equipment in less than ten months from program initiation, and at a cost of less than $3,000/pound (compared to some $100,000/pound for comparable astronaut-rated payloads). A key to the efficient and cost-effective approach was the use of the Universal Small Experiment Container or USEC™ developed by Wyle Laboratories. This commercially-developed product was used to incorporate the furnace, vacuum system, computer/controller, power conditioning, cooling system, pressurized gas purge system, gravity sensor, and other elements into a compact 220-pound package. The project has established a new milestone by demonstrating how more cost-effective payloads can be developed and flown on the Space Shuttle.

BACKGROUND

Wyle Laboratories is a founding member and industrial partner in a NASA-sponsored Center for Commercial Development in Space (CCDS). The University of Alabama in Huntsville-Consortium for Materials Development in Space (UAH-CMDS) was established in 1985 to support efforts to commercialize the processing of materials while taking advantage of the unique low-gravity conditions which prevail during space flight. The Consortium has developed and demonstrated an automated isothermal furnace that processes metal composites at temperatures exceeding 1,100°C. This furnace system is named the Equipment for Controlled Liquid Phase Sintering Experiments (or ECLiPSE). It has flown on Consort sub-orbital rocket flights (Missions 4, 5, and 6) which helped to advance the furnace technology for further applications.

The ECLiPSE furnace system incorporates a stainless steel ampoule which holds eleven metal samples containing a mixture of metal powders. It is designed to combine composites of hard metals in a tough metal matrix to gain the excellent wearing properties of the hard material and the strength of the tough material. Applications include improved bearings, dental tools, electrical brushes, magnetic devices, and contact points. A prime application of commercial interest is for the multi-billion dollar machine tool industry, where improvements in the wear capability of cutting tools could realize sizable gains in productivity.

In early 1992, the Consortium was offered the opportunity to adapt the ECLiPSE furnace system to fly in a Space Shuttle mission on board the first commercial SPACEHAB module. This unique module was designed to accommodate small commercial payloads compatible with the Shuttle Middeck locker arrangement. Wyle Laboratories, under contract to the UAH-CMDS, redesigned and redeveloped the ECLiPSE sounding rocket system for operation in the manned space environment of the Space Shuttle which requires much more stringently controlled conditions than needed for sounding rocket payloads.

Using a number of innovations, management techniques, and unique equipment, Wyle delivered the astronaut-rated payload in less than ten months and at a cost far less than that of payloads with similar complexity and capability. This paper describes the technical and programmatic approaches that were used to achieve a new milestone in space payload development.

ECLiPSE-HAB DESCRIPTION

The ECLiPSE-HAB furnace system is based on design concepts used on the Metals and Alloys Solidification Apparatus (MASA) developed by Wyle Laboratories. It is an essential part of the UAH-CMDS and Wyle strategy for development of economical and versatile furnace systems to meet the needs of commercial space programs. In addition, the rugged furnace has flown on several Consort sub-orbital rocket missions which were sponsored by NASA and the UAH-CMDS. Dr. James E. Smith is the UAH Principal Investigator and researcher most responsible for incorporating ECLiPSE into the Consort and SPACEHAB missions. In addition to Wyle, other contributions have been made by the Kenemetal Corporation and Teledyne Wah Chang (through provision of metal samples) and by Parker Hannifin and Automatic Switch Corporation for providing unique components. The ECLiPSE-HAB stainless steel furnace assembly (see Figure 1) can process up to eleven powdered metal samples (1.1 cm length and 1.9 cm diameter) during each sintering cycle. It is designed to melt the pre-compressed samples, while under low-gravity conditions, and through precisely controlled thermal conditions, it allows the metal samples to resolidify. Sintering in the microgravity environment provides a more uniform microstructure by removing normally found sedimentation and stratification layers based on gravitational effects.

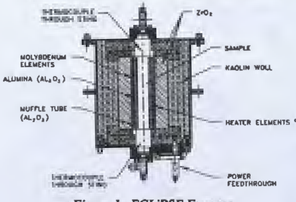

Figure 1. ECLiPSE Furnace

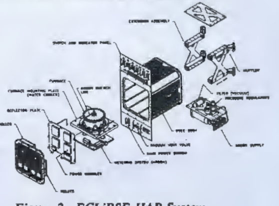

Figure 2. ECLiPSE-HAB System

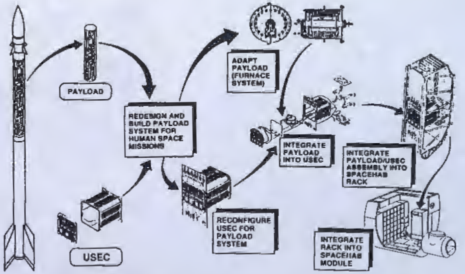

Figure 3. Transitioning of a Sounding Rocket Payload to a Human Space Mission

The ECLiPSE-HAB system includes the sintering furnace, a computer, a cooling system, a vacuum system, a network of electrical/electronic parts and assemblies, a containment system, a structural support system, control panels, and a pressurized gas purge system (see Figure 2). These elements had to be designed, engineered, fabricated, tested, integrated, and documented under precise specifications and engineering controls not required by a sounding rocket program. Figure 3 provides an overview of the transition process required to adapt the sounding rocket ECLiPSE furnace experiment to the SPACEHAB mission.

A unique pressure vessel called the Wyle Universal Small Experiment Container, or USEC™, was used for containment of the furnace and other components to meet NASA safety requirements. It is an available commercial product that has multiple uses and reduces payload development time. Wyle developed the USEC™ system to provide a standardized, inexpensive containment system for small, commercial payloads to fly aboard the Space Shuttle (in the Middeck, SPACELAB, or SPACEHAB) or on the Space Station (Express Rack for small payloads). The USEC™ enabled the design and integration team to meet the extremely short development schedule by becoming the key structural element of the furnace assembly. Due to thermal, outgassing, and flammability considerations, the USEC™ is evacuated during flight operations. In essence, the USEC™ became the containment vessel and the "strong-back" for the experiment itself. A support structure was used on the back of the USEC™ to help stiffen up the rack as well as to provide a platform for the argon system, the Three-Dimensional Microgravity Accelerometer, and other components.

ECLiPSE-HAB has upper and lower panels to accommodate electrical control switches, valves, control handles, and status lights. The upper panel, also accommodates the payload general support computer plug used for data communications.

ECLiPSE-HAB fits into a payload rack assembly developed by McDonnell Douglas Aerospace Corporation for SPACEHAB (see Figure 4). A special support structure, designed by Wyle, attaches to the rear members of the rack. Chilled water for cooling is provided to the furnace assembly from a pump and heat exchanger in the bottom of the rack. A high fidelity mockup was also developed and provided to NASA JSC for astronaut training purposes.

During its operational cycle, Space Shuttle crew members monitor the control panel indicators and furnace progress. ECLiPSE-HAB is first evacuated, pressurized with argon gas, and then the furnace is activated. It autonomously heats to a temperature in excess of 2000°F, which is above the melting point of one of the metals in the composite samples. The samples then undergo rearrangement and solution re-precipitation followed by purge, heat-up, processing, quench, and cool-down cycles. The total time for all operations is about 10 hours.

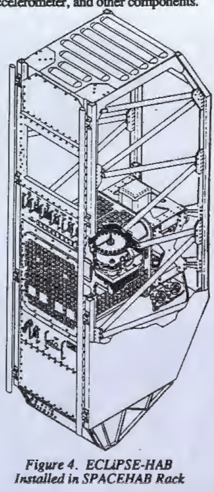

Figure 4. ECLiPSE-HAB Installed in SPACEHAB Rack

USEC™ TECHNOLOGY

Wyle Laboratories began the USEC™ development in 1988. Due to the existing small payload traffic for the Space Shuttle and that anticipated for the Space Station, Wyle embarked on the USEC™ project as a commercial venture. Several design criteria were formulated to guide the development. Simply stated, these were: that USEC™ would be a pressure vessel to minimize risk and enable simpler apparatus to fly in the manned environment; USEC™ would be capable of accepting all resource interfaces; USEC™ would provide maximum volume and lightweight construction to enable more payload weight to be carried per volume; USEC™ would be accommodatable by any known carrier (walls, racks, cargo bay carriers) through standardization of footprint and support structure; USEC™ would provide ease of access to the payload; USEC™ would enable rapid integration and deintegration (ground or on-orbit); USEC™ would provide standard internal fittings and payload adaptation hardware. These design criteria were used to drive out several candidate designs.

Numerous trade studies were conducted to ferret out the best (most practical and cost-effective) combinations of materials, manufacturing processes, mounting structures, internal payload accommodations fixtures and methods, resource interface ports, and sealing methods. Another factor that was vital to low cost was the number of qualified lives (missions). The greater the number of lives, the higher would be the development cost, and that would translate directly into higher lease price. On the other hand, if the USEC™ were to be qualified for only one or two lives that also means a higher lease price. A vast number of manufacturing processes and methods were technically analyzed and tested. These ranged from welding, castings, honeycomb structures, and others. The USEC™ configuration shown throughout this paper was the most overall effective concept and the one carried through to full development.

Universality is a major feature of USEC™. It can accommodate a large population of the NASA Small and Rapid Response (SARR) payloads that presently exist as well as those planned for Space Station. It is universal in that it can be mounted on the Middeck wall, SPACEHAB wall, SPACEHAB double or single rack, standard Spacelab rack, SMIDEX rack, any other cargo bay carriers, and the Space Station EXPRESS rack. Figure 5 shows the basic USEC™ payload containment system.

Modularity is another USEC™ feature that has appeal. A USEC™-enclosed payload can fly as a part of a mission of opportunity. If the originally-intended location or previous location was, for example, the Spacelab rack (which is manifested four years in the future), and if an opportunity to fly in the Middeck in two years became available, USEC™ could easily accommodate this change. Other aspects of the modular approach are the ease of handling, integration, and deintegration both on the ground and on-orbit.

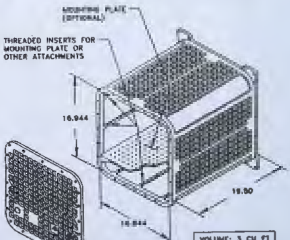

Figure 5. Wyle Universal Small Experiment Container (USEC™)

USEC™, as shown in this paper, is USEC™-Model 1 that fits neatly into the space of two Middeck lockers. Other USEC™ models are under development. Model 1 can carry internally about 60 pounds of payload in the wall-mounted configuration and approximately 90 pounds in a rack configuration. It provides roughly three cubic feet of payload volume, can be outfitted with internal structures to accommodate practically any payload configuration and orientation required. Custom-designed front and rear doors with practically any type resource penetration to handle a variety of connectors and fittings are provided to meet the customer's requirements.

USEC™ Technology is much more than a simple box. In fact, there were five engineering transformations in the process of transforming a box into the USEC™ which is a payload containment system with embedded or designed-in intelligence. This is referred to as "embedded intelligence" because it allows a payload developer to develop a "not-so-intelligent" payload and "not-so-expensive" a payload. It will enable a simpler, less costly experiment to fly in the manned environment of the Space Shuttle in a much shorter time. Figure 6 illustrates the transformation processes.

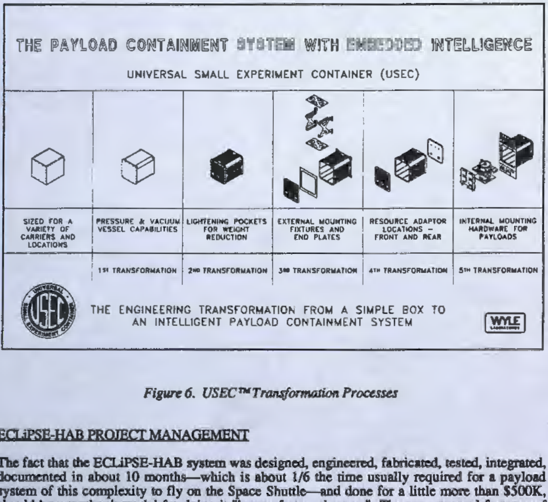

Figure 6. USEC™ Transformation Processes

ECLiPSE-HAB PROJECT MANAGEMENT

The fact that the ECLiPSE-HAB system was designed, engineered, fabricated, tested, integrated, documented in about 10 months—which is about 1/6 the time usually required for a payload system of this complexity to fly on the Space Shuttle—and done for a little more than $500K, should be a textbook model for doing it "better, faster, cheaper." There are several features of Wyle's approach that were fundamental to our program. Wyle "Coyote-Works" characterized the development team and its modus operandi. The features that follow characterize the team members.

- Each team member was a "real expert" (i.e., unique contributor) in the assigned area of responsibility or discipline area. These areas included Structural Analysis, Thermal Analysis, Electronics/Control Systems, Computer-Aided Design, and Safety Engineering.
- Each team member had to be a one-person work force which required them to:
  - Lay out the models, work, etc.
  - Develop software (where necessary)
  - Operate the software
  - Understand NASA requirements relevant to his/her work
  - Assure that work was performed in accordance with NASA requirements
  - Participate with other engineering team members in payload/experiment "hands-on" assembly, testing, integration, etc.
- Each team member recognized that success or failure fell squarely on his/her shoulders...
  - Team members understood that the company had high expectation levels
  - Team members were proud of their accomplishments
  - No one wanted to be the weak link responsible for team failure

The key to the organizational approach of the "Coyote Works" is summarized by the following features:

- Very shallow organizational chart
- Manager was a worker (technical contributor)
- Manager assisted the engineering team members by removing obstacles, reducing administrative activities, ensuring that problems were dealt with immediately (allow no "problem" to have shelf-life)
- Meetings were held only to resolve problems and to ensure that all team members stayed on the agreed-to schedule
- All members were physically located close together (partitioned work areas/offices, not a bullpen)

The project goals were SMART:

- Specific
- Measurable
- Attainable (and challenging)
- Relevant (individual to team and vice versa)
- Time-based (deadline sparks productivity)

Finally, there were the Wyle factors. Some of these are inherent in the Wyle corporate culture and Wyle's traditional way of doing business. Other factors were unique to this project and represented the "Coyote Works" concurrent engineering approach. These factors were as follows:

- Wyle is a commercial/industrial company that competes in the free enterprise system for most of its work. (Very little Government work.)
- Wyle was success-driven to demonstrate that we could do it "faster, better, cheaper."
- Wyle thought that the development (i.e., concepts, design, fabrication, assembly, testing, integration, analytical NASA documentation) of a complex payload system in less than 10 months for about $500,000 (less than $3,000/pound) would showcase our accomplishments and lead to more work.
- Job was Fixed-Price.

A point worth emphasizing is that the "Coyote Works" team had no technicians nor blue-collar workers. The engineering team did all of the "hands-on" work with the exception of the machining activities. In short, it would have been too costly and time-consuming to have had to train technicians or to write procedures for them to use to do the work, and to oversee their work. The culture of some companies due either to unions or otherwise will not allow engineers to get involved in the detailed "hands-on" assembly and integration. Our experience, however, has indicated engineers want this kind of involvement. Also, who could do it better than the ones that developed it ?

Another important ingredient was Wyle's close working relationship with Dr. James Smith and his UAH-CMDS group. The two groups worked like one coherent team. Also, SPACEHAB, Inc. provides a user-friendly carrier. SPACEHAB's payload integration contractor, McDonnell Douglas, was instrumental in smoothing the way for ECLiPSE-HAB and all the payloads in the SPACEHAB module.

RESULTS

The ECLiPSE-HAB furnace has operated successfully during its space flight missions and has produced excellent samples. Iron/copper, cobalt/copper, and copper/nickel/tungsten specimens have been processed in low gravity and analyzed. Uniform dispersion, lack of cracking, less densification, and other superior features have been realized. Also, microgravity conditions have helped to decouple the sintering mechanisms which can enhance numerical modeling techniques and help us to better understand and improve ground-based sintering processes.

Based on the results of the first SPACEHAB mission, several small changes were incorporated into the ECLiPSE-HAB system prior to reflight. In addition to sample changeout, the control system software was modified to provide a different time interval for furnace processing. From this, a more comprehensive understanding of the relationships between time, temperature, and microgravity effects on the sintering process can be realized.

The ECLiPSE-HAB system is now qualified and available for future flights in the Space Shuttle. Although it has been used only for liquid metal sintering experiments, the system can easily be adapted to other investigations that require the use of an automated isothermal furnace for low gravity investigations.

PLANS

The ECLiPSE-HAB furnace system has proven to be a versatile tool for gaining more comprehensive insights into the relationship between melting/solidification of metal composites under both low and normal gravity conditions. Improvements to the furnace system are being explored to extend its temperature range and operational times to provide a thermal gradient, and allow manual or automated changeout of additional samples on-orbit. Advanced versions will be based on the space flight proven design and operational features which have already been developed and demonstrated.

Advanced versions of the ECLiPSE furnace system are being considered for use in the planned international Space Station (with possible precursor operation aboard the Russian MIR Space Station). The long-term objective includes development of not only space furnaces needed for research and experimental studies, but to achieve large-scale materials processing in space through the use of large solar-thermal furnaces and production of completely new materials based on the unique environment available in space. (See Reference 5 for an additional discussion about large solar-powered space furnaces.)

ACKNOWLEDGMENTS

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